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Visual Acuity and Stereopsis

with Night Vision Goggles

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By

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Sensory Research Division

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Measurements of visual performance (stereopsis and visual resolution) were acquired to compare results achieved using unaided monocular and binocular viewing, monocular and binocular viewing with the AN/PVS-5A night vision goggles, and models A and B of the AN/PVS-7 biocular night vision goggles. All of the goggles were equipped with 2nd generation tubes. Using a modified Howard-Dolman apparatus to assess stereopsis, all of the goggle-assisted thresholds were very much larger than stereoscopic thresholds achieved with unaided binocular vision. Statistical analysis of the results indicated that stereopsis through night vision goggles, regardless of the model or viewing condition, is essentially eliminated and equivalent to the threshold obtained with unaided monocular viewing. In comparison, spatial resolution capability with all of the goggle systems is superior to performance with unaided vision. In agreement with previously published data, visual acuity with the goggles is approximately 20/50, but only for high contrast
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targets and simulated full moon ambient light levels. As light levels decrease to quarter moon conditions or target contrasts are reduced to more realistic values, visual spatial resolution with the goggles is much poorer. Statistical analysis of the results indicates that a biocular night vision system causes no further visual penalty on stereopsis or visual acuity than binocular or monocular designs. For infantry use, any differences in visual performance between monocular, biocular, and binocular designs probably are not operationally meaningful.

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Introduction

The demonstrated commitment to improving military night operations through the development of light amplification devices has been extraordinary. Mobility and capability have been enhanced greatly because the vision-limited operational envelope has been extended to starlight levels by light amplification devices. Although third generation technology recently has been developed for the AN/AVS-6 night vision system for Army aviation, the most generally available and widely used light amplification system is the second generation AN/PVS-5 night vision goggles (NVGs).

Recent development efforts managed by the Center for Night Vision and Electro-Optics (CNVEO) have been directed toward designing new NVGs for infantry use. The goal of these new developments is to produce a system providing acceptable performance at reduced unit cost. The result of these efforts has been the development of the AN/PVS-7 (A and B models). To reduce costs, the optical design of both models is biocular.

Figure 1 displays a schematic picture of various optical designs possible for viewing devices. As shown, a biocular design consists of a single sensor/light amplification system and two eyepieces so that the observer views with both eyes. With a biocular, both eyes receive the same image of the viewed scene from a single sensor, whereas a binocular design presents slightly different images to the two eyes. While biocular viewing provides input to both eyes, it does not share some of the advantages of actual binocularity.

For example, the basis for stereopsis, the binocular appreciation of depth, is the neural fusion of images arising from slightly disparate views from the two eyes. Also, binocular visual acuity has been shown (Campbell and Green, 1965; Home, 1978) to be superior to monocular acuity presumably because of the statistical advantage of having two independent input comparators, i.e. the images from both eyes. Obviously, the single sensor design of a biocular should preclude these binocular advantages, particularly for stereopsis.

Scene

Binocular   Biocular   Monocular
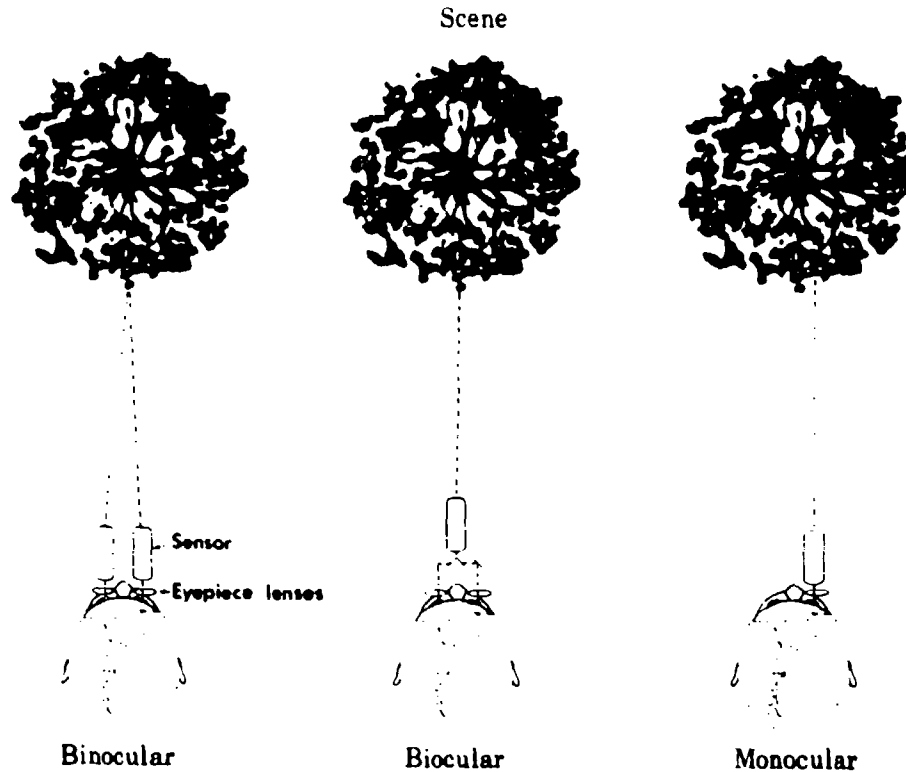
Figure 1. Schematic diagram of binocular, biocular, and
monocular optical designs used with light
amplification electro-optical viewers.

The CNVEO requested that U.S. Army Aeromedical Research
Laboratory (USAARL) investigate man-goggle visual performance
with the AN/PVS-7 models and compare the resulting data with
similar data obtained using the AN/PVS-5 goggles. The AN/PVS-7
goggles were equipped with second generation tubes similar to
those in the AN/PVS-5 goggles. The AN/AVS-6 system with third
generation amplification tubes was excluded from this study
because of its different spectral responsivity (Pollehn, 1988).
These differences are apparent in Figure 2. The third
generation, AN/AVS-6, system has an improved spectral
sensitivity in the infrared portion of the electromagnetic
spectrum taking advantage of energy normally available in the
night sky. Since this spectral emission which might adequately
duplicate the night sky spectrum is not yet available in a
cathode ray tube phosphor, to include the third generation
technology in laboratory tests using video imagery would

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yield invalid measurements of performance of the third
generation tubes.

The purpose of this report is to provide the results of
our laboratory comparisons. Data are presented to compare
stereopsis performance and visual acuity using unaided
monocular and binocular vision, monocular and binocular viewing
with the AN/PVS-5A NVGs, and models A and B of the AN/PVS-7
biocular goggles fitted with second generation sensors.
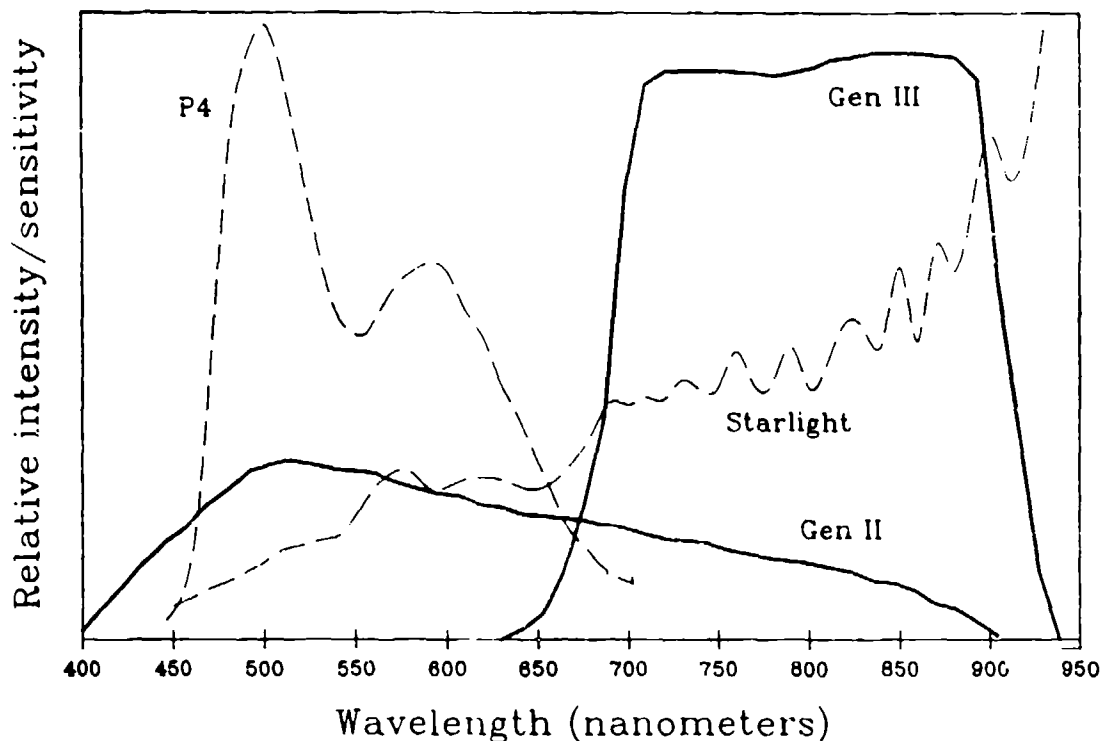
Figure 2. Comparison of sensitivities of second generation and
third generation light amplification tubes.
Spectral content of night starlight sky and a P4
cathode ray tube phosphor are shown as dashed lines.

Methods

Stereopsis measurements

For all stereopsis measurements, a modified Howard-Dolman
apparatus (Figure 3) was used which required the observers to
indicate when two vertical rods, one in a fixed position and
the other moveable, were observed as aligned in a frontal-
parallel plane. Modifications to the basic instrument
consisted of driving the variable-positioned vertical rod by a

motor controlled by a radiofrequency receiver. The observers
held a transmitter and moved a toggle switch in a fore and aft
direction to initiate rod movement and effect alignment with
the fixed comparison rod. When an observer indicated the rods
to be aligned, displacement readings to the nearest 0.1 mm were
taken with a digital voltmeter indicating the voltage across a
linear potentiometer attached to the variable rod. Except for
a 0.75° x 1.75° viewing window in the front of the instrument,
the apparatus was enclosed completely and illuminated with
electroluminescent panels lining the sides and top of the
enclosure. The luminance levels were set to 7 footlamberts for
naked eye observations and 0.012 footlambert for all
observations using the various NVGs.
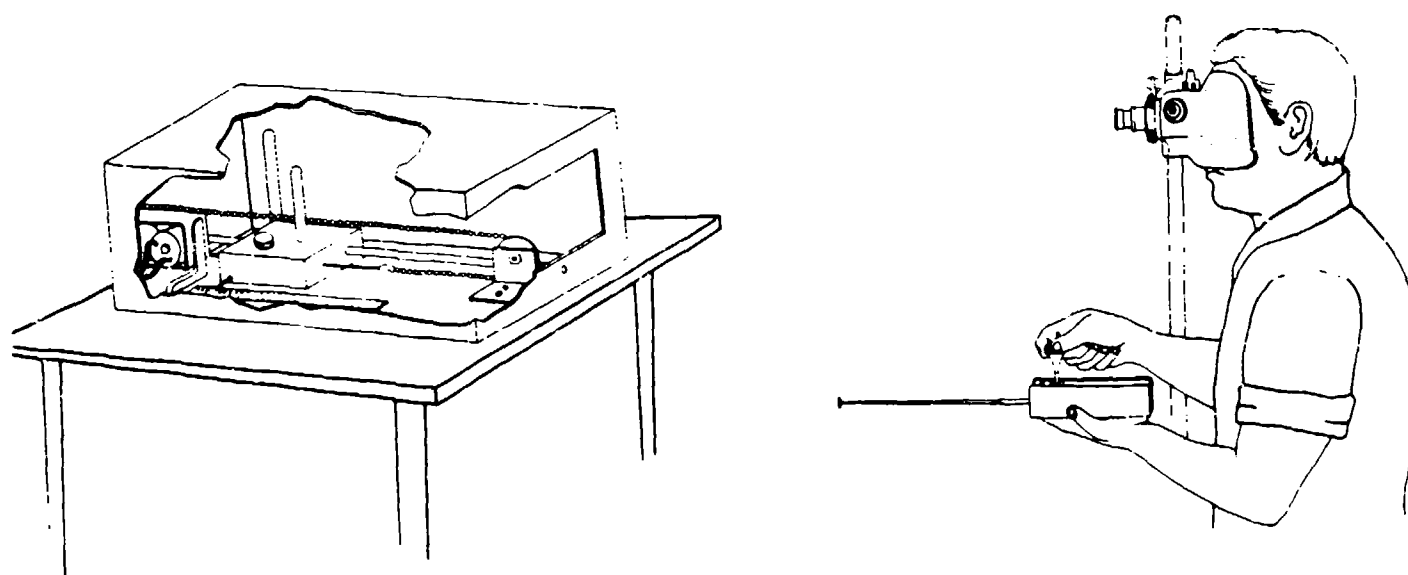
Figure 3. Picture of an observer remotely adjusting the
moveable vertical rod of the Howard-Dolman
apparatus.

Ten young adult subjects participated as observers in
these experiments. None of the subjects previously had tested
with the Howard-Dolman apparatus and had only marginal
experience with the NVGs. The sole selection criterion was
that an observer demonstrate 20/20 monocular Snellen acuity
without correction on standard high contrast test charts. Each
subject participated in two measurement sessions, each lasting
approximately 45 minutes. A modified method of adjustment was
used and during each testing block, an observer would make 10
determinations of alignment with each of the 6 viewing

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conditions: unaided monocular, unaided binocular, monocular AN/PVS-5, binocular AN/PVS-5, AN/PVS-7A, and AN/PVS-7B. All of the monocular measurements were achieved by occluding the nonpreferred sighting eye for unaided observations or the tube in front of the nonpreferred eye for goggle measurements. Before each observation, the variable rod was moved to either forward or rearward from the fixed rod by a preassigned random schedule. To reduce serial effects, the order of the viewing conditions was counterbalanced between subjects. All observations were made at a viewing distance of 6 meters.

The standard deviations of linear displacement scores were used to represent stereopsis thresholds after the technique originally described by Hirsch and Weymouth (1948). While that measure has recently been questioned (Larson, 1985), we have continued to use the standard deviation to indicate stereopsis thresholds since it has received more universal acceptance and it will allow us to compare our results with previous investigations. These linear thresholds are converted to angular measures using the following equation:

$$\eta = \frac{a \ (\Delta d)}{d^2} \cdot 206,280$$

where

η = angular threshold in seconds of arc
a = interpupillary distance
Δd = linear displacement of the variable rod from the fixed rod
d = observation distance

Visual acuity measurements

As in the stereopsis comparisons, 10 young adult observers participated as subjects for the visual acuity measurements. Some, but not all, observers participated in both studies. Again, our only requirement was 20/20 unaided visual acuity for each eye. The same six viewing conditions, appropriately counterbalanced to obviate serial effects, were used for the acuity measurements which required two experimental sessions of approximately 60 minutes each to complete.

For these observat:· the subject was seated comfortably in a darkened room ill. ed only by the output from a video display monitor at a di. e of 6 meters from the subject. A Snellen optotype "E" wa. isplayed on the screen for 500 msec in one of four possible orientations and the subject indicated the orientation of the "E" by positioning a joystick. The experimenter controlled the size of the letter displayed on the monitor but not the orientation. Orientation of the "E" was random and under microprocessor control. The experimenter

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ensured that each of the "E" targets, ranging in sizes corresponding to Snellen notations of 20/400 to 20/10 (minimum angles of resolution: 20 to 0.5 minutes of arc), was presented 10 times.

In addition to the six viewing conditions previously mentioned, several additional variables were added which greatly increased the number of acuity thresholds obtained. The display monitor brightness was adjusted with neutral density filters which covered the display to simulate full moon and quarter moon luminance levels (10^{-3} and 10^{-4} candela per square meter, respectively) and target contrast was adjusted electronically to present "E" targets having contrasts of 94, 35, or 5 percent. [For this investigation, target contrast is defined by the following equation: ratio of the difference to the sum of the maximum and minimum brightness.] A total of 36 viewing conditions (6 goggles x 2 moon levels x 3 target contrasts) were provided to obtain visual acuity thresholds. The measurement of interest was the percentage correct response for each target size. Thus, a cumulative ogive was generated by each subject for every viewing condition. Our threshold acuity was the target size which was observed correctly 62.5 percent which is simply the 50 percent point after adjusting for chance correct with the four alternative, forced-choice procedure.

Results

Stereopsis

The results of the stereopsis measurements for all viewing conditions are displayed in Figure 4. The best or lowest angular threshold was achieved with unaided binocular viewing followed, in order, by binocular AN/PVS-5, monocular AN/PVS-5, unaided monocular, AN/PVS-7A, and AN/PVS-7B. The threshold values obtained with the monocular and binocular unaided and AN/PVS-5 NVG viewing conditions are quite similar to thresholds measured in a previous study (Wiley et al., 1976). The biocular NVG models were not available for inclusion in that study. Using Scheffe's S-multiple comparison statistic to evaluate these data, a significant difference (p<.01) exists only between the unaided binocular condition and the other viewing conditions. No statistically significant difference was found between the remaining five viewing conditions.

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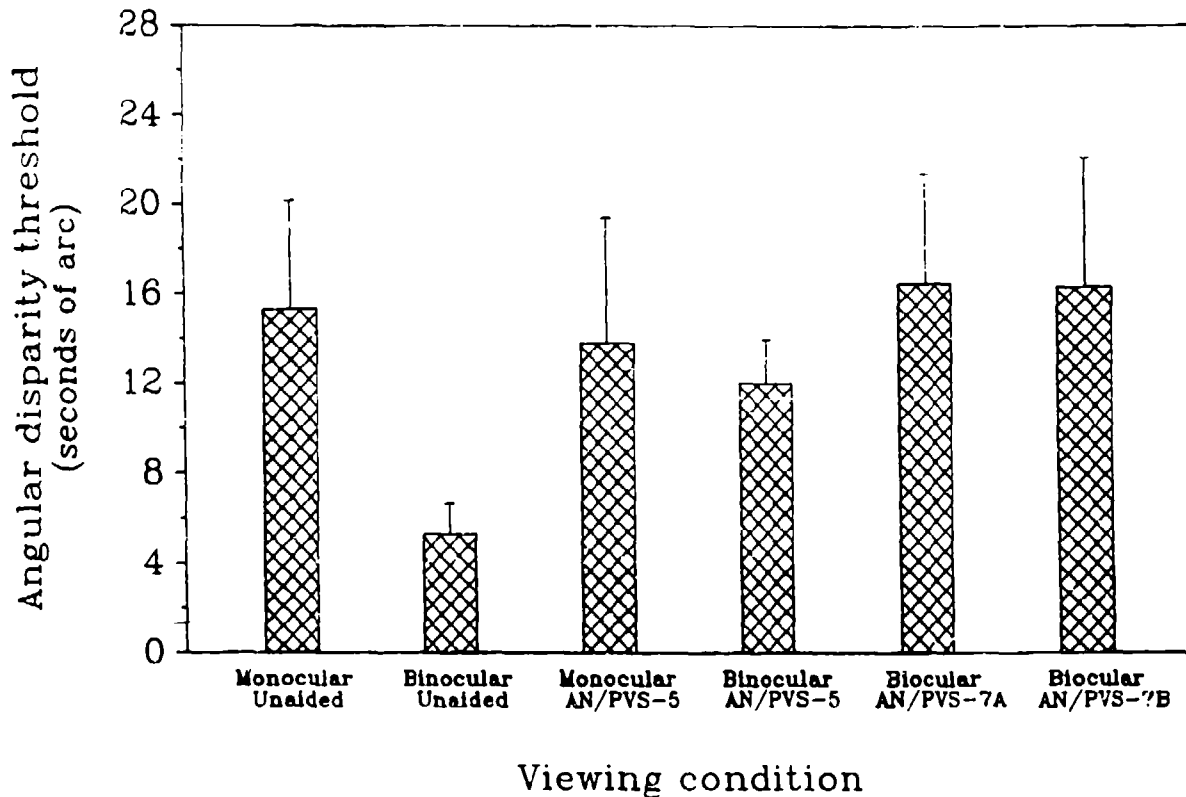
Figure 4. Stereopsis disparity thresholds (seconds of arc) for the different viewing conditions. Each threshold is the average from 10 observers with the bracket extending above each bar indicating +1 standard deviation.

Visual acuity

Although these experiments were designed to yield six acuity thresholds (three target contrasts for each of the two ambient lighting conditions) with each of the six viewing conditions, our results fell short of expectations because subjects had difficulty resolving targets of low contrast with reduced ambient luminance. The largest target presented was equivalent to a 20/400 Snellen letter. This letter size subtends 100' and provides a minimum angle of resolution (MAR) of 20'. Our subjects were unable to resolve even this large target when it presented 5 percent contrast using unaided vision under full moon ambient conditions. With quarter moon conditions, the subjects could not resolve the targets at any of the three contrasts with their unaided vision. In fact, the 5 percent contrast target could not be seen even with the light intensification devices at the quarter moon level.

The acuity results for full moon luminance and the various viewing conditions are shown in Figure 5. The minimum angle of resolution scores are shown on the left ordinate with the corresponding Snellen acuity shown on the right. Arbitrary scores of 20' MAR were assigned those viewing conditions when several observers were unable to resolve even the largest targets. The most striking feature of Figure 5 is the disparity between acuity performance in the unaided viewing conditions and performance with the light amplification devices. For example, under full moon conditions, unaided performance for the 94 percent contrast target was approximately 20/130 and 20/90 Snellen acuity for monocular and binocular viewing, while acuities with the light amplification devices were approximately 20/50 Snellen. The disparity increases as the acuity task becomes more demanding. With 35 percent target contrast, the respective acuities for unaided monocular and binocular viewing were 20/275 and 20/210, while the goggle-assisted acuity centered around 20/70. As stated above, using unaided vision some subjects were unable to resolve even the largest of the low contrast (5 percent) targets while the acuity with the various goggle configurations varied between 20/160 and 20/200.
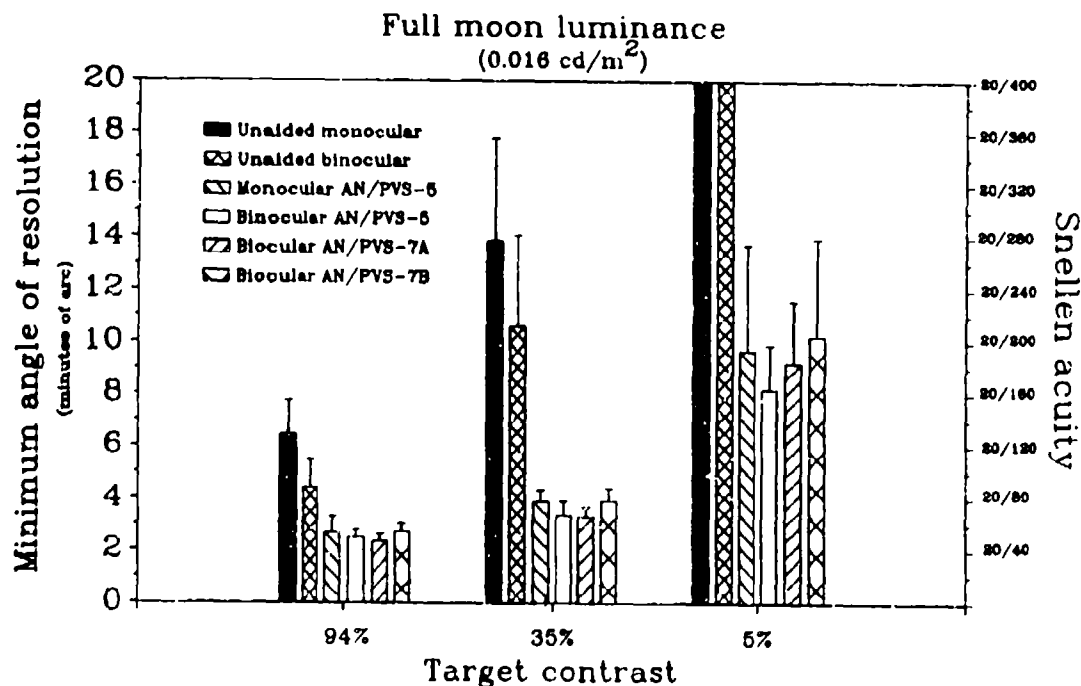
Figure 5. Visual resolution with simulated full moon ambient luminance and three target contrasts. Each acuity value is the average from 10 observers with the bracket extending above each bar indicating +1 standard deviation.

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The acuity results obtained when the ambient luminance was equivalent to that provided by a quarter moon are shown in Figure 6. As mentioned previously, the 5 percent contrast target could not be resolved with quarter moon luminance. Many of our subjects could not resolve the largest of the 94 percent and 35 percent contrast targets using unaided vision. Accordingly, the average acuity performance was assigned a value of 20' MAR for these conditions. For the 94 percent targets, goggle-assisted acuities ranged between 20/60 and 20/75. Using 35 percent contrast targets, the acuities varied from 20/95 to 20/120.

Quarter moon luminance
(0.0016 cd/m²)
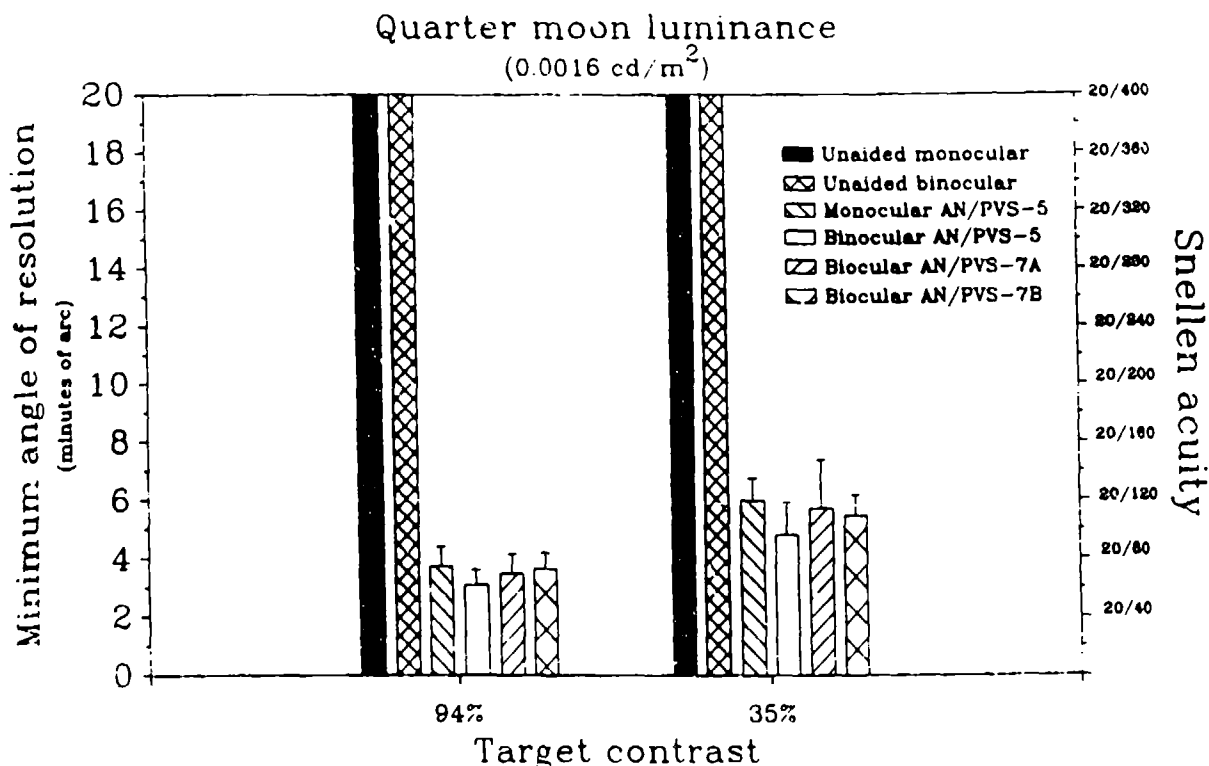
Figure 6. Visual resolution with simulated quarter moon ambient luminance and two target contrasts. Each acuity value is the average from 10 observers. Brackets indicate +1 standard deviation.

Discussion

The primary thrust of these investigations was to assess two primary aspects of visual performance using different configurations (monocular, biocular, and binocular) of second generation night vision goggles and to compare that performance with data obtained using unaided monocular and binocular

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vision. The biocular design developed recently for infantry use has an obvious cost-savings advantage since it would require a single sensor. However, no quantitative visual performance measures have been available. The two aspects of visual performance evaluated in the present tests are stereopsis and spatial resolution. Both functions should yield differential performances depending upon the viewing conditions and goggle configurations.

Stereopsis is the perception of a depth dimension based on lateral separation of two eyes causing slightly disparate views (retinal images) of a single object. When the images from the two eyes fuse into a single percept, the object is normally appreciated in its relative depth position in the visual scere. While stereopsis requires input from two eyes, depth perception normally occurs with contributions from monocular cues, e.g., overlay, haze, texture gradient, etc., in real world viewing. The Howard-Dolman apparatus was designed to measure pure stereopsis thresholds although some monocular cues provide minor contributions. Of the various techniques presently available, e.g., polarized stimuli, anaglyphic image separation, etc., the Howard-Dolman is the only measurement of stereopsis designed for optical infinity which is compatible with night vision goggles. The Armed Forces Vision Tester (AFVT) provides a slide to assess stereopsis at infinity. Unfortunately, interfacing the optics of the NVGs with the AFVT introduces error and the acuity demands for the test exceed the resolution capability of the NVGs. Near point measurements of stereopsis cannot be used with the NVGs because of the fixed alignment of the binocular goggles for optical infinity without convergence.

A recent publication (Larsen, 1985) has provided discussion questioning the validity of measurements using the Howard-Dolman instrument. However, after considering the options available and our objections to other methods, we concluded that the Howard-Dolman technique provides thresholds which are quantitative and reliable (Sloan and Altman, 1954). The results shown in Figure 4 are not unexpected and are similar to thresholds reported previously (Wiley et al., 1976). The threshold achieved with unaided binocular viewing is clearly superior to thresholds found with the other viewing conditions. Thresholds measured with the five remaining viewing conditions are not significantly different and are essentially identical to the unaided monocular viewing threshold.

In practical terms, stereopsis achieved with biocular viewing is statistically equivalent to that found with binocular NVG viewing. Cost-savings can be accomplished by

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reducing the number of sensors in the NVGs from two to one without further penalizing the ability to perceive depth through stereopsis. However, it is important to note that all of the goggle systems tested essentially eliminate stereopsis. The relative contribution of stereopsis to the appreciation of depth becomes increasingly important with closer viewing distances where disparity angles are larger for objects with fixed linear separations (Hirsch and Weymouth, 1947; Teichner, Kobrick, and Wehrkamp, 1955; Wiley et al., 1976). These closer viewing distances are critical during helicopter operations such as hovering and landing. That is, for those critical viewing distances where the appreciation of depth is most important, stereopsis provides an increasingly important contribution to the overall perception of depth. Helicopter aviators must be aware that while viewing with night vision goggles their stereopsis cues, on which they have relied principally during unaided binocular viewing, essentially are eliminated. They must compensate for this loss by placing greater reliance on other (monocular) cues. This requires aviators undergoing NVG training be exposed to this loss and learn to compensate with other perceptual cues and aircraft instrument information available.

In comparison to the stereopsis data showing a loss of visual ability while using the NVGs, the visual acuity measurements (Figures 5 and 6) reveal the considerable improvement in spatial resolution capability when using NVGs under reduced illumination conditions. Ability to resolve spatial details is much superior with all of the NVG conditions compared to performance with unaided vision. For all viewing conditions, performance is decreased when stimulus information is degraded either by decreasing ambient luminance (full moon to quarter moon) or decreasing target contrast. Acuity performance with the binocular NVG under degraded stimulus conditions (quarter moon, 35 percent target contrast) is approximately equivalent to unaided binocular vision under the best stimulus conditions (full moon, 94 percent contrast) used in this study.

The advantage of having two independent viewing channels, i.e., binocular viewing, for spatial resolution can be seen in comparing spatial resolution performance with the four goggle viewing conditions. Average performance is best with the binocular goggle condition and the difference in performance among the four conditions becomes greater as the stimulus is made dimmer or reduced in contrast.

Spatial resolution capability with NVGs has been cited as a minimum angle of resolution of 2.5 to 3.5 minutes of arc, corresponding to Snellen acuity of 20/50 to 20/70 (Wiley and

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Holly, 1976; Price and McLean, 1985). The results of this investigation corroborate that level of spatial resolution, but only for high contrast targets. Unfortunately, high levels of contrast are probably unrealistic for real world conditions. Objects in nature seldom present such a high contrast. While natural scenes have a variety of contrasts, most objects present contrasts of 25 to 50 percent (Pollehn, 1988). Therefore, the present acuity values obtained in a laboratory using high contrast targets can be somewhat misleading to the NVG user. The acuity performance using 35 percent targets is probably more realistic. In the present study, the acuity was 20/70 (3.5' MAR) for the 35 percent contrast targets under full moon conditions and dropped to approximately 20/100 (5' MAR) under quarter moon conditions. These values were obtained with the binocular viewing condition. Monocular goggle viewing performance was slightly poorer. Visual resolution performance using the lowest (5 percent) contrast targets also is interesting. This low contrast can be related to the target presented by a wire against a dark sky. Under full moon conditions, low contrast acuity performance was only 20/200 (10' MAR) and the largest targets (20/400) available in the present study could not be resolved with quarter moon ambient luminance.

Figure 7 is a summary graph combining binocular NVG data from the present investigation with additional data obtained by Levine and Rash (1989) under similar conditions. The decay in acuity performance with decreasing target contrast is readily apparent in this figure. The performance values shown in these investigations were obtained under optimal conditions. All of the observers had 20/20 uncorrected vision; the goggles were focused precisely for the appropriate viewing distances; the laboratory environment was quiet, comfortable, and free from stress. Visual performance during actual flight operations most probably is poorer with the NVGs than the data reported here would suggest (Miller et al., 1984).

Perhaps a more important question than expected visual performance using NVGs concerns minimum visual performance required for helicopter flight operations. The questions frequently raised are, "How much vision is necessary for helicopter flights?" or "How good do electro-optical viewing devices need to be?" These seemingly straightforward questions are really quite complex. These questions have not been answered by the present investigation or any other data available and probably cannot be answered with any acceptable validity. The first step would be to define the expected flight operations. The visual requirements for navigation or troop transport would be different than those requirements for insertion operations, air-to-ground combat or air-to-air combat operations. These latter operations probably would have more
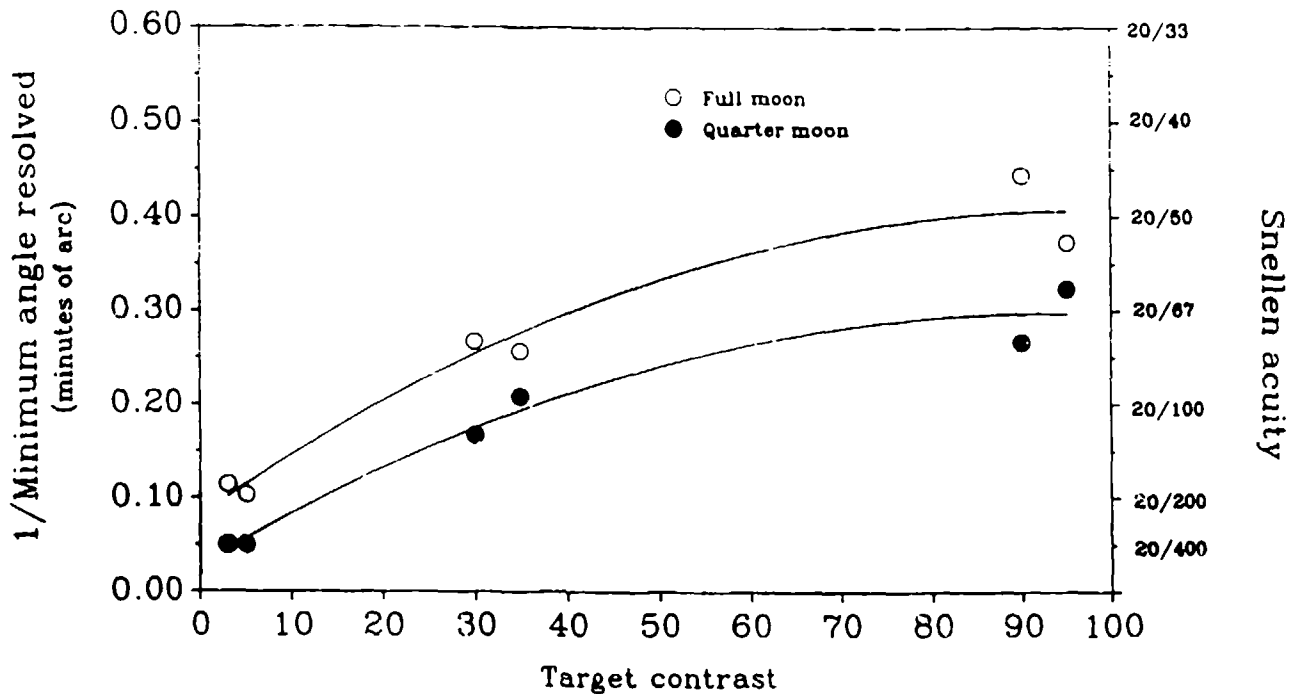
Visual acuity with AN/PVS-5A NVGs

Figure 7. Binocular visual acuity with the AN/PVS-5A night
vision goggles as a function of target contrast.
Data are replotted from the present investigation
and combined with data from Levine and Rash (1989).

demanding visual requirements. The most difficult problem is
that of laboratory si...ulation of these requirements. Simply
stated, the various possible visual demands cannot be simulated
in any acceptable global fashion to provide precise prediction
of expected performance or performance requirements. What
remains then to provide guidance to the optical designer or
material developer is experience and reason. Based on 10+
years of Army aviation experiences with NVGs, it is reasonable
to conclude that the visual performance allowed by the present
models of NVGs is acceptable for effective flight operations.
Future designs should, as a minimum, allow visual performance
equivalent to that provided with the present designs. Improve-
ments in visual performance with future electro-optical systems
designs will yield improved flight safety and operational effec-
tiveness. The most significant contribution to safety and opera-
rational effectiveness is made by training and the judgement ex-
ercised by the aviator controlling the aircraft. Electro-optical
viewing devices do not turn night into day for the aviator. That

is not necessary. However, it is necessary that aviators are trained thoroughly to appreciate the differences in the visual scene presented by these devices so that appropriate compensations can be made. Operational effectiveness and flight safety will be achieved by training, reason, planning, and common sense.

Conclusions

The present data confirm previous findings that stereopsis, the appreciation of a depth dimension using input from both eyes, is greatly reduced or eliminated when viewing with night vision goggles. Stereopsis performance is statistically equivalent with the three optical designs (monocular, binocular, and biocular) tested.

Spatial resolution performances were much superior when using all of the goggle designs compared to unaided visual performance. With the number of subjects tested, the differences between acuity scores using the three optical designs failed to reach statistical significance. However, the binocular design yielded slightly better visual acuity scores, especially when target contrast or ambient luminance was reduced. Acuities using either the biocular or monocular designs were practically identical.

These results indicate that a biocular design electro-optical night vision system imposes no further visual penalty on stereopsis or spatial resolution than other electro-optical systems. For infantry use, any differences in visual performance with binocular or biocular optical designs probably are not operationally meaningful.

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